The TESLA Dogbone Damping Ring

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for the TESLA Collaboration

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Outline

The Dogbone

Issues:

- Kicker Design
- Dynamic Aperture
- Emittance Dilution due to Stray-Fields
- Collective Effects
  - Space Charge
  - Impedance
  - Ion effects
  - Electron Cloud

The TESLA Bunch Train

- SC Technology:
  - long RF pulses and thus long bunch trains
  - low frequencies and thus small wake-fields

Benefits:

- High power transfer efficiency
- Straight forward intra-train feedback
- Relaxed LINAC tolerances

Requires a damping ring (system) which is capable of damping the approximately 1 ms long bunch train at once.

The TESLA Bunch Train

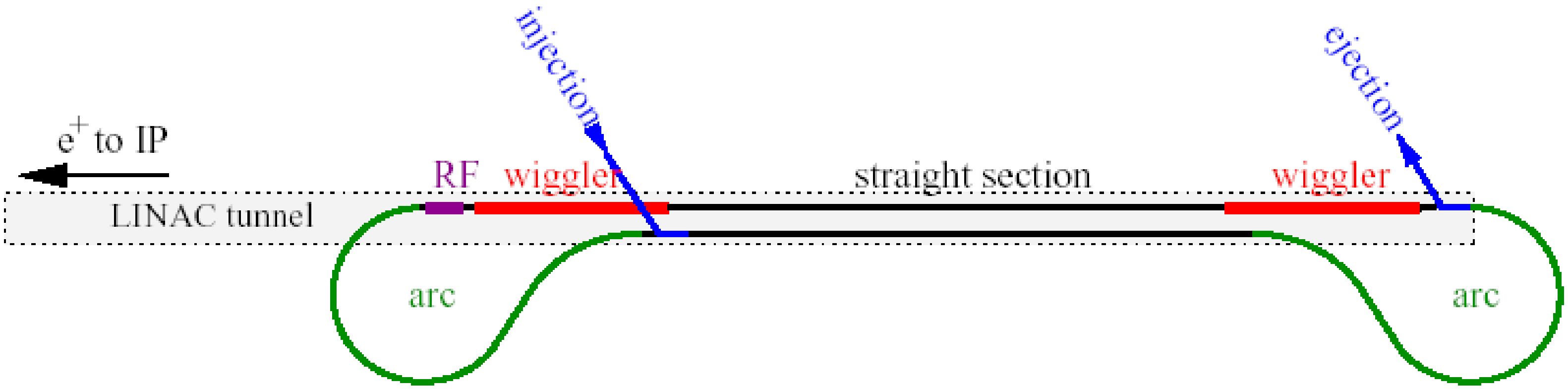
- TESLA bunch train 2820 × 337 ns = 950 μs

  ⇒ 285 km long

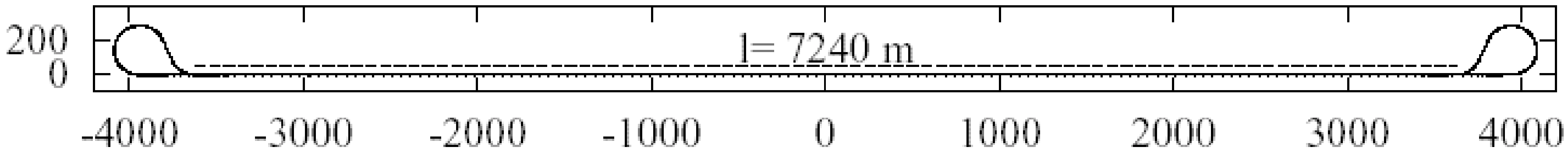
- Extract every bunch separately, bunch spacing given by shortest kicker rise/fall time

  ⇒20 ns × 2820 ≈ 56 μs ⇒ 17 km long

- Save tunnel cost: DR in main linac tunnel and short return arcs ⇒ dogbone



Dogbone Design



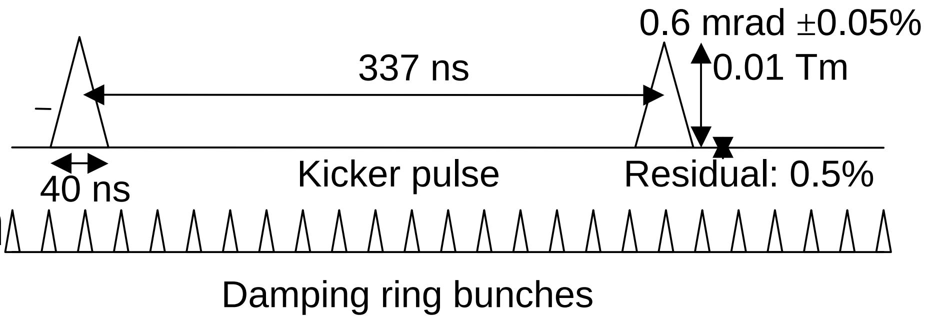
- **Arc lattice** defines momentum compaction (bunch length), chromaticity correction, small emittance
- **Wiggler** section to provide damping
- **Long straight** as simple transport line

- Very flexible design: more wigglers, collimation, length chicane,…
- Large energy (5 GeV) to mitigate space charge effects
  - No Intra-beam scattering
  - Touschek-lifetime 30 min

Kicker R&D (1)

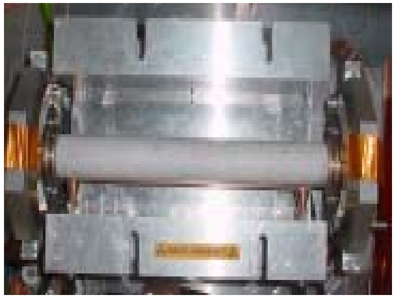
Kicker specifications

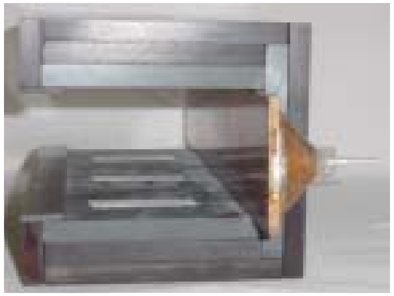
- 0.05% amplitude stability
- 3MHz pulses, 5Hz repetition



Kicker technology available

- Strip-line
- Ferrite loaded C-yoke





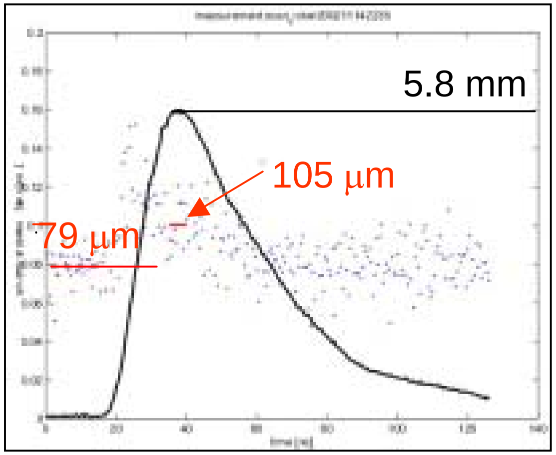
Pulser development based on commercial available MOSFET switches (Behlke)

Kicker R&D (2)

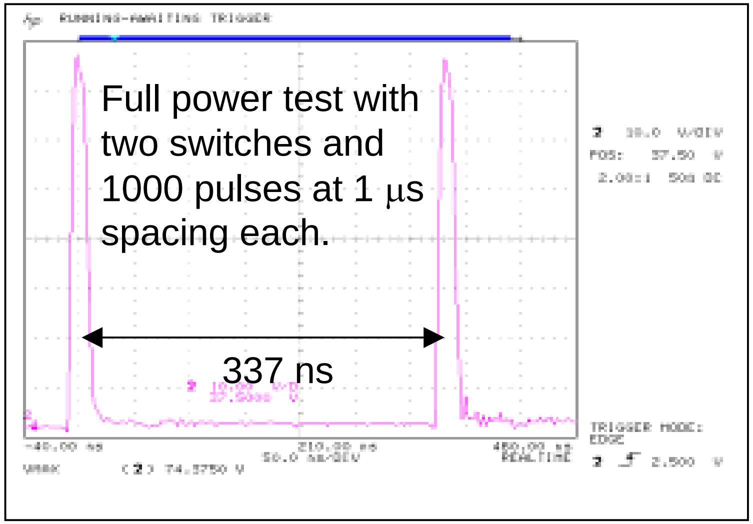
Kicker system measurements with beam at TTF 1

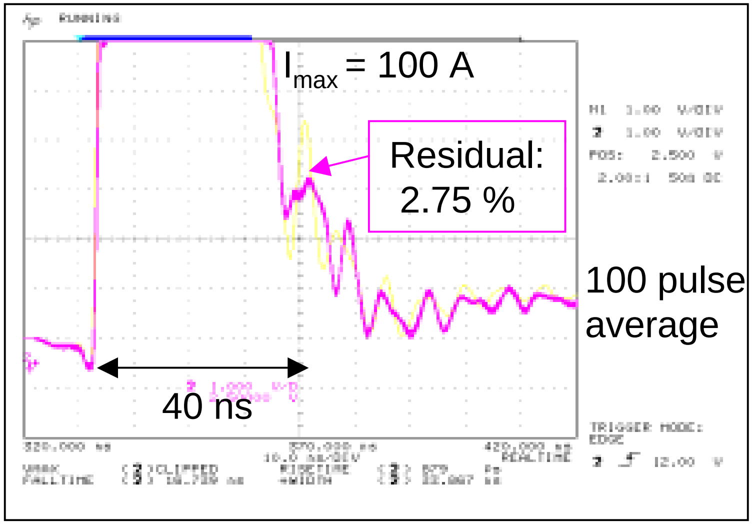
- measurement of kicker strength with BPM
- scan of the kicker pulse width with a timing step of 0.5 ns
- 30 pulses for each data point
- Measured amplitude jitter (1 Kicker) : 1.2%

30 Kicker : 0.2 %



Pulser results





Kicker R&D (3)

	System Specification	Kicker Measured	Next Steps
Pulse length	40 ns	30 ns	
Rise time (10%-90%)	8 ns	4.9ns	
Micro pulse	3 MHz	2 MHz	3 switches parallel
Macro pulse	5 Hz	5 Hz	
Amplitude stability (1/10 σ_x)	0.05 %	1.2 % (0.2% for 30 kickers)	•No effort so far •Apply clipping techniques •Apply 180deg kicker
Residual kick	0.5 %	2.75%	Beam based correction

Fast kicker prototype successfully tested

Dynamic Aperture

Incoming positron beam emittance requires large acceptance

- Possibility to over produce e^+ and collimate

Dynamic aperture limited by wiggler insert

Optimize wiggler parameters

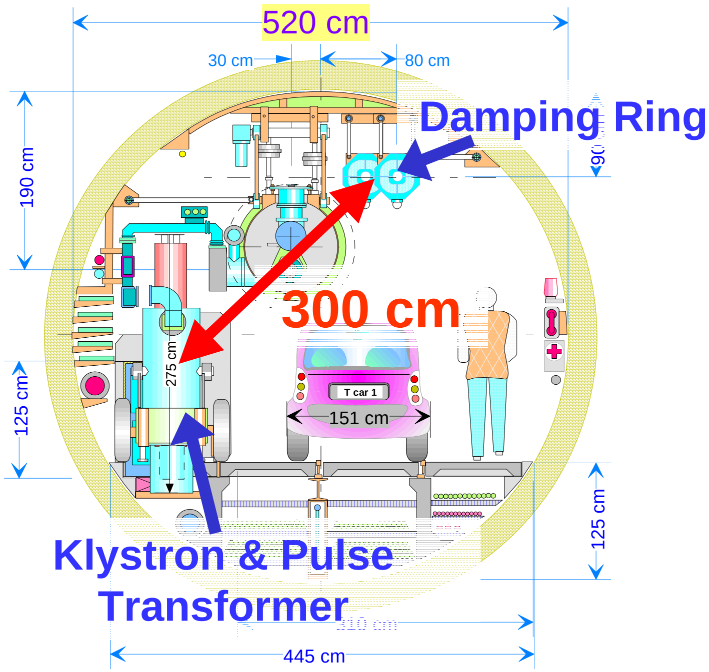
- Optimisation of wiggler field shape has never been done
- Increase of wiggler period length (>40cm) possible

Optimize lattice design

- Smaller beta-functions
- Insert non-linear elements (octupoles)

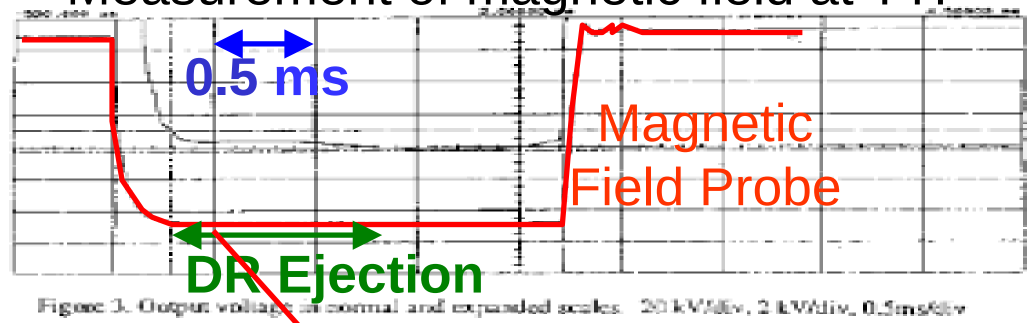
Rings with lots of wiggler damping are operating (CESR) or will come into operation (PETRA III, 2008)

Time Varying Stray Fields (1)

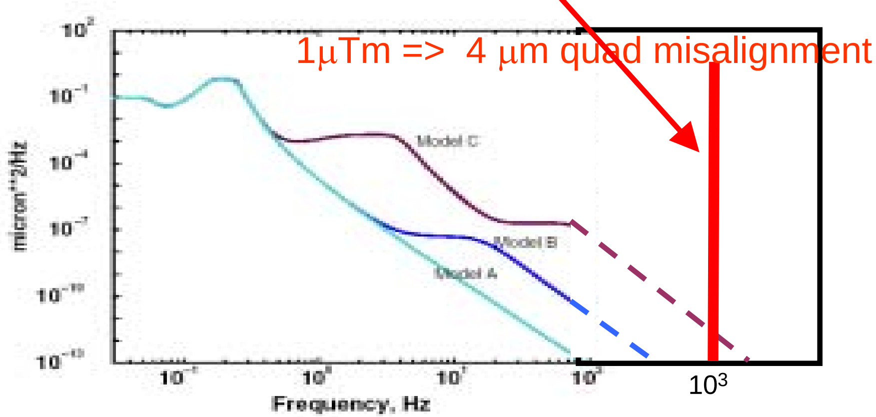


Magnetic fields arising from LINAC pulse cause orbit/dispersion perturbation at ejection

Measurement of magnetic field at TTF

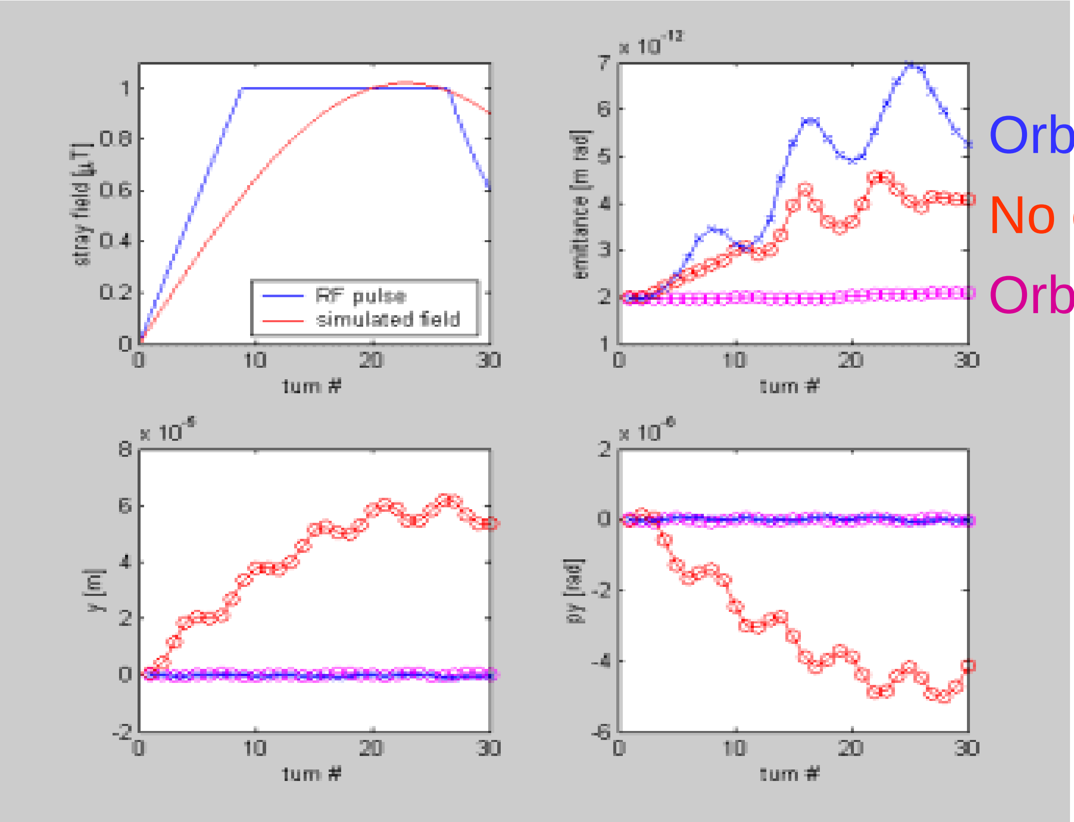


Ground motion power density spectrum



Time Varying Stray Fields (2)

Simulation of ejection process



Orbit correction at Ejection Point

No correction

Orbit & Dispersion correction at EP

Worst case scenario: average factor 2.5 in $\varepsilon_y \Rightarrow < 30\%$ lumi loss

Time Varying Stray Fields (3)

Cures:

- Shielding (magnetic shielding difficult but eddy current shielding possible (2cm Cu/Al))
- Repetitive component (most?) can be compensated by fast kicker scheme (2 fast dispersive bumps in/at extraction)
- Second tunnel solution for DR (adds roughly ~150 MEuro)

Space Charge Tune Shift (1)

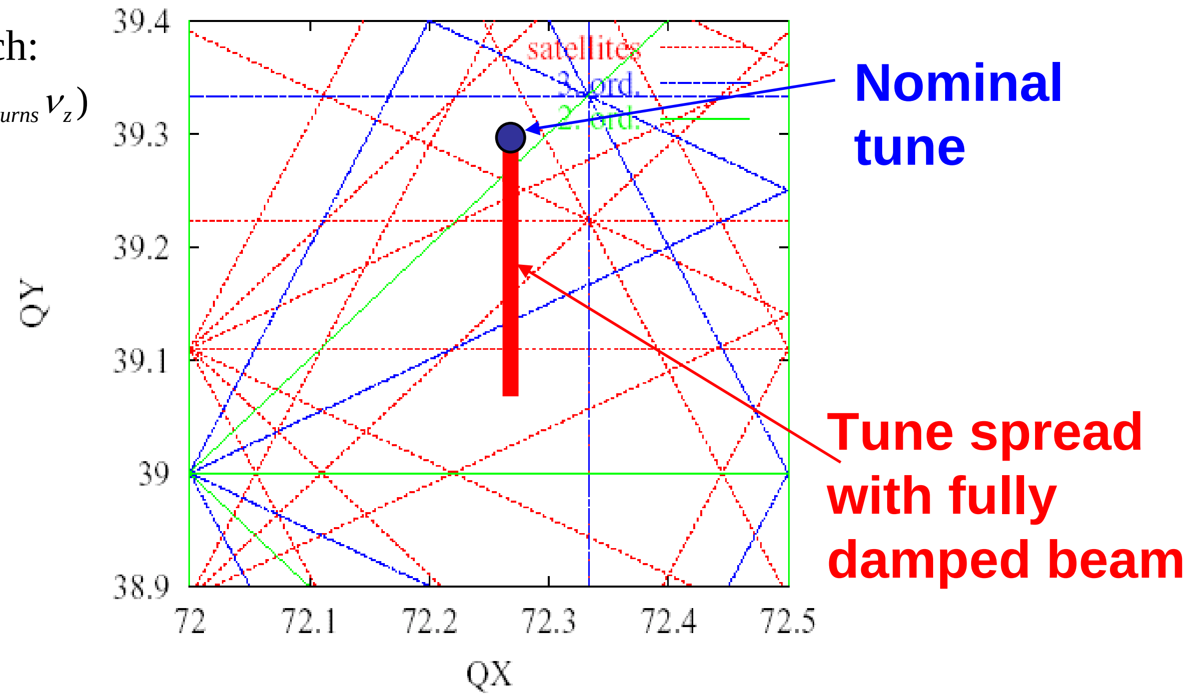
Longitudinal position within bunch:
Synchrotron oscillations $z = z_o \cos(2\pi \#_{turns} \nu_z)$

Circumference: large

$$\boxed{\Delta Q \propto \frac{C N_e}{\gamma^2 \sqrt{\varepsilon_x \varepsilon_y}} \frac{e^{\frac{-z^2}{2\sigma_z^2}}}{\sigma_z}}$$

Energy: small

Emittance: small



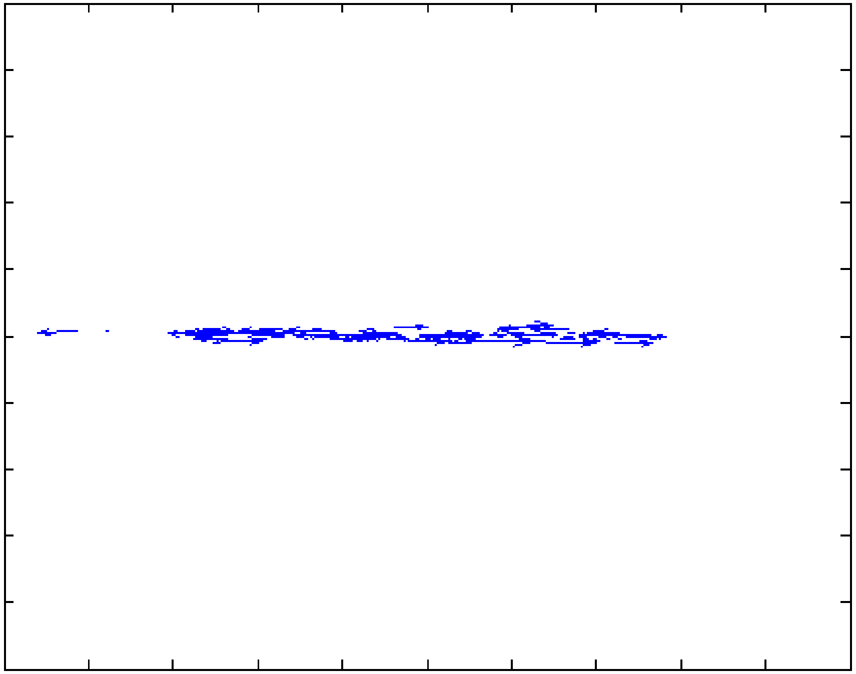
- Direct space charge force large because C/γ^2 is unusual large
- Synchroton oscillations vary the particle position within the bunch, leading to incoherent tune spread, increasing while the beam is damped
- Particle amplitude growth when crossing resonances

Space Charge Tune Shift (2)

- **Proton synchrotrons operate with incoherent tune spread around 0.5**
- **Experience from PETRA II proton synchrotron**:
  - Proton beam energy 7 GeV
  - Incoherent tune spread 0.1
  - Lifetime about 5 – 10 minutes
- **A tune spread below 0.1 prevents amplitude increase**
- **Decrease the space charge tune shift:**
  - Increase ε_y by factor 4 (always works)
    - This is worst case scenario, leads to 40 % lumi loss
  - Increase energy (difficult arc lattice, more RF,….)
  - Decrease ring length (kicker, e-cloud, ions)
  - Increase beam size locally

Space Charge– Local Coupling

1. Skew quadrupole triplet
2. Straight section (Linear Optics)
   Inverse skew quadrupole triplet
3. Inverse skew quadrupole triplet

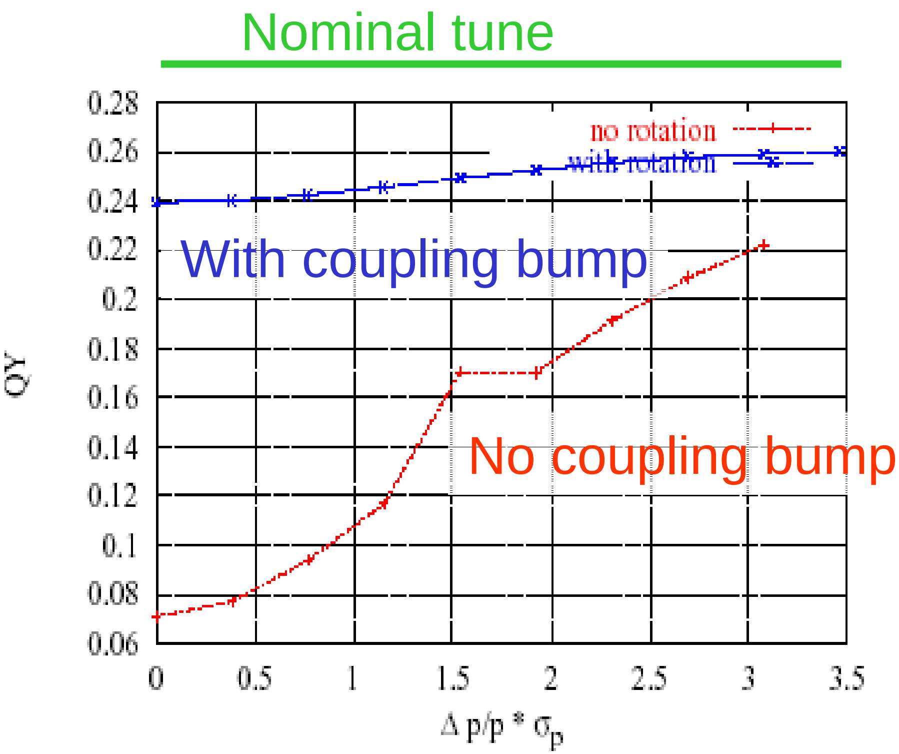


Red: No local coupling
Blue: Local coupling

- **Simple, tunable linear optics**
- **$\nu_x - \nu_y < 0.02$ gives 10% emittance increase**
- **Solenoid compensation in colliders more advanced, nevertheless betatron coupling ratios of well bellow 0.5% reached (DAϕNE, LEP, …)**
- **Orbit/Dispersion correction requires 4×4 algorithm**

Space Charge - Tracking Results

- Application of **coupling bump keeps space charge tune shift below 0.1**
- **No amplitude increase observed** in tracking



Particle tune versus initial longitudinal amplitude

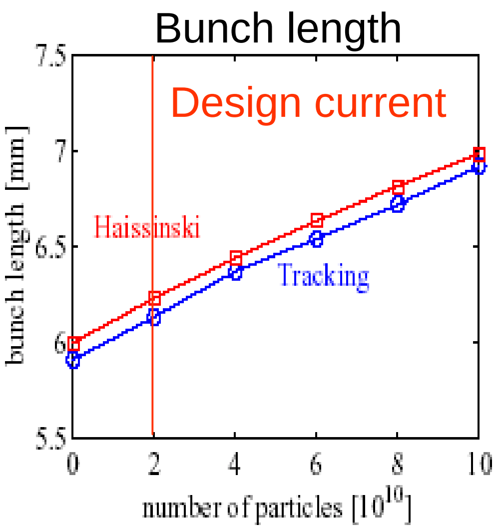
Collective Effects-Single Bunch

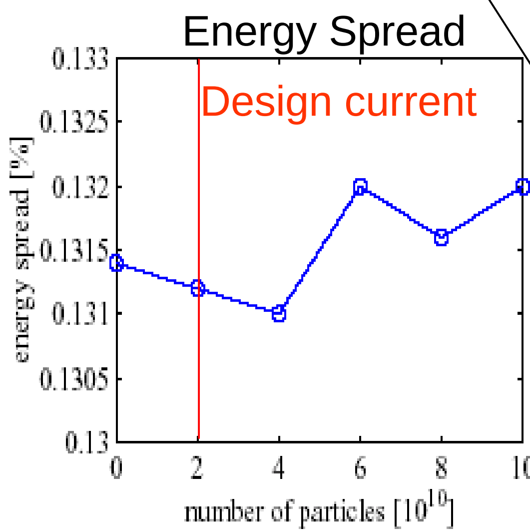
- **longitudinal microwave instability**
  factor 5 below threshold from tracking
- **bunch lengthening**
  not observed in tracking simulations

Impedance budget

Non-inductive components	$Z_{\|\|}/n$ mΩ
RF cavities	2.0
Resistive wall	5.4
Kickers	≈ 17
Total	≈ 25

Inductive components	$Z_{\|\|}/n$ mΩ
Bellows	≈ 11
BPMs	≈ 12.5
Other components	≈ 5
Total	≈ 28.5





$Z_{\|\|}/n$ is the effective impedance (machine impedance averaged with bunch spectrum) per unit length

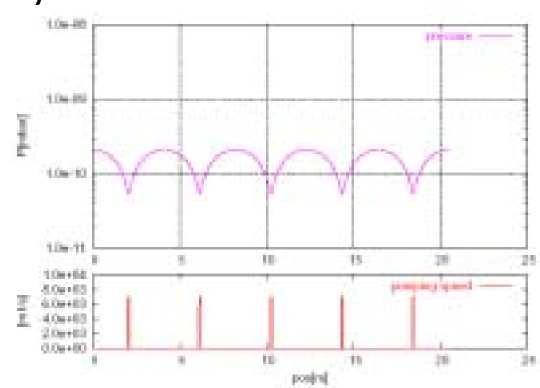
- transverse mode-coupling threshold 96,000 KΩ, $Z_{\perp} \approx$ 4,000 KΩ

Ion Effects

- TDR design pressure of 10^{-9} mbar
- **Ion Trapping:** Train gap of $\approx$**600 ns** needed to clear ions
- **Tune Shift:** In straight accumulated ions produce a **tune shift of 0.28** at end of bunch train.
- **Fast Ion Instability:** Calculated growth time of the order of 100 μs (for all DR). More studies needed.

Cures:

- Vacuum pressure of 10^{-10} mbar in straight, 10^{-9} mbar in arc
  - More pumps, ante-chamber in arc
  - Cost increase
- Intra-train clearing gaps



Ion effects can be mitigated by proper vacuum system design

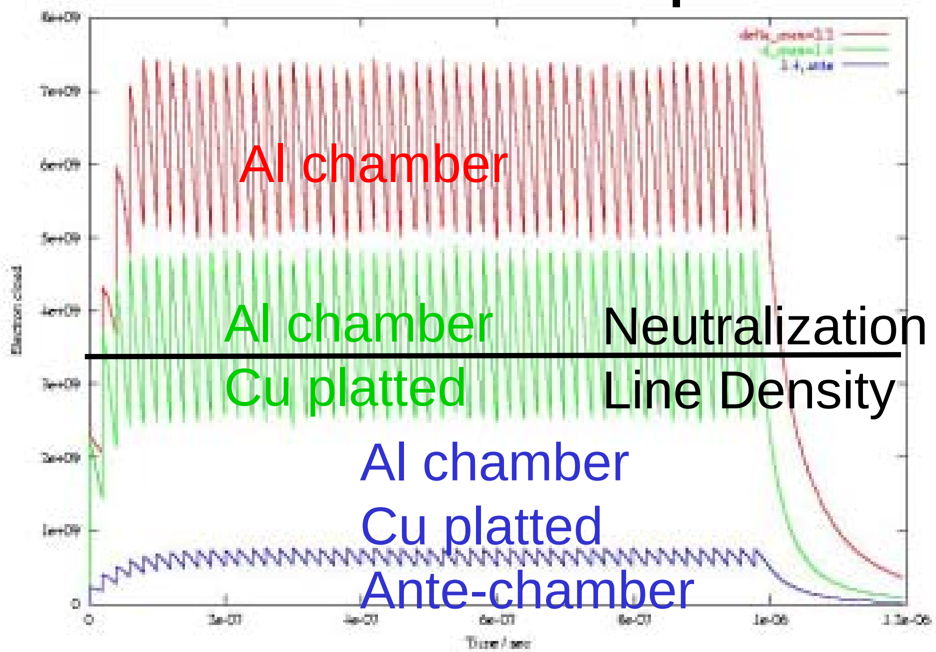
Electron Cloud

- E-cloud is a world-wide observed and studied effect (next ICFA workshop April, part of EuroTeV proposal), with controversy results
- Issue for all DR, large TESLA Dogbone bunch-spacing helps preventing the e-cloud build-up
- Machines which suffered from e-clouds found ways to mitigate the effect
- E-cloud effects studied in collaboration with CERN

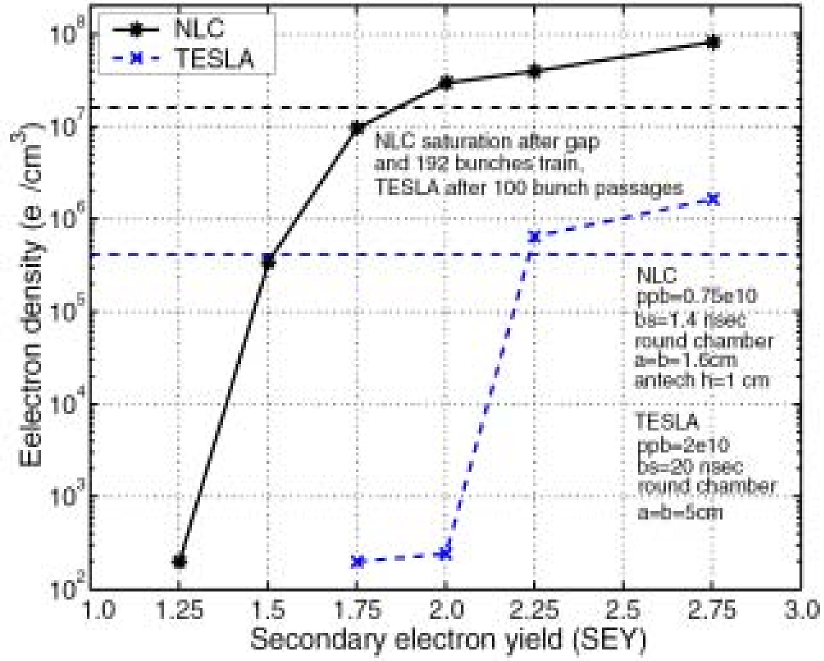
- Build up of the electron cloud occurs depending on
  - Vacuum chamber layout (geometry, ante-chamber,…)
  - Vacuum chamber material (Secondary emission yield)

Electron Cloud – Build Up

Electron Cloud Build Up in Arc

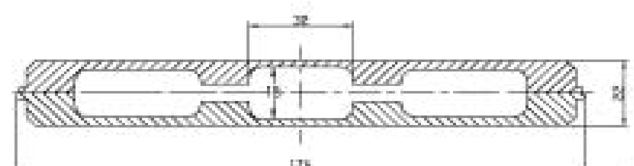


Electron Cloud in Straight



Wiggler Section

- Ante-chamber design in the TDR
- Trapping of electrons in some sections of the wiggler observed in some simulations



Electron-Cloud Induced Instabilities

Effective wake leading to strong head-tail instability calculated assuming various e-cloud densities

	Arc	Straight	Wiggler	**TEASLA DR**
Length / m	1900	14560	540	17000
Scenario 1: neutralization density everywhere				
cloud charge density / 10^{12} m^{-3}	2.7	0.4	5.8	0.85
effective wake field / threshold wake	0.577	0.59	0.359	**1.526**
Scenario 2: neutralization density in wiggler				
cloud charge density / 10^{12} m^{-3}	0.75	0.01	5.8	0.28
effective wake field / threshold wake	0.161	0.014	0.359	**0.521**

50 % above threshold

100 % bellow threshold

- Single bunch head-tail instability threshold not reached even with neutralization in wiggler
- Multi-bunch growth rate within damping capabilities of MBFB system

E-cloud effects in the TESLA e^+ DR can be mitigated by proper design of the vacuum system

ILCTRC Ranking 2 – All DR

- Simulation studies and experiments to understand the magnitude of electron cloud effects
  - Worldwide effort going on (ICFA, EuroTeV, …)
- Further simulations and experiments of the fast ion instability
  - To be performed
- Damping ring extraction kicker stability (at level of <10-3) requires continued studies including experiments
  - Prototype build, test at TTF or PETRA possible
- Additional simulations of emittance correction in the damping rings are needed as well as experiments in existing machines
  - Continuing effort, experiments at light sources, ATF, PETRA and HERA possible

ILCTRC Ranking 2 – TESLA Specific

- Development of a damping ring kicker with very fast rise and fall times
  - Prototype build and successfully tested
- Further dynamic aperture optimization of the ring
  - Optimization of wiggler etc. to be performed

  ("This issue requires an aggressive effort to optimize the TESLA DR wiggler and/or lattice design. Such an effort is expected to produce a satisfactory solution", ILCTRC)
- Energy **and luminosity upgrade** to **800 GeV** puts tighter requirements on DR alignment tolerances, and on suppression of electron and ion instabilities. Further studies are required.
  - 800 GeV parameter set to be adjusted

Summary

- TESLA Dogbone is a cost-effective solution for the TESLA damping ring
- Mature design including industrial studies for many components
- Based on world-wide experience with storage rings
- Unique features attract attention of many accelerator physicists world-wide
- ILCTRC has not identified any showstoppers